HAVEN & JAHN

Measurement of Water by means of the Vertical Jet

Municipal and Sanitary Engineering

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MEASUREMENT OF WATER

BY MEANS OF THE VERTICAL JET

BY

CLARENCE IRWIN HAVEN
AND
HARRY FRANCIS JAHN

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

MUNICIPAL AND SANITARY ENGINEERING

COLLEGE OF ENGINEERING

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June 1, 1912

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLARENCE IRWIN HAVEN and HARRY FRANCIS JAHN

ENTITLED MEASUREMENT OF WATER

BY MEANS OF THE VERTICAL JET

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science In Municipal and

Sanitary Engineering.

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Instructor in Charge

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UIUC

6 Inch Orifice on 12 Inch Short Tube.
Showing Operator at Work.

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MEASUREMNET OF WATER BY MEANS OF THE VERTICAL JET.

DESCRIPTION OF VERTICAL JET APPARATUS. In practice, an orifice on top of a short tube which is fastened to an enlarged section in which baffles can be placed is the condition met in the measurement of the flow of water by means of the vertical jet. The enlarged section is made by means of an increaser and decreaser. The measuring apparatus will almost always be placed just beyond an elbow. As a result of this the flow will be through one side of the orifice if there are no baffles used.

The apparatus on which the experiments were made was made up as shown in Pl. 1. Six inch pipe was used, and the enlarged section was nine inches in diameter. The baffle board was 1 1/4-inches thick and had 154 3/4-inch holes spaced about 3/4-inch centers. A differential mercury gage was connected to the apparatus just below the orifice and below the last bend so as to show the loss of head through the bend and baffle. It was intended at the beginning of the experiments to record these losses but because even at the highest heads on a five inch orifice it was inappreciable the writers deemed it advisable not to take the losses into account. For separating the sheet of water as it fell back into the box a piece of sheet tin about twelve by fifteen inches in size placed in the sheet of water so as to divert it to each side was used. This enabled the operator to reach under and measure the jet with a pair of calipers. The tin shield was securely fastened to an arm which could be raised or lowered according to the head, by means of a small set screw which was clamped to a vertical rod which was fastened to the base of the jet apparatus. In order to support the calipers at any desired height a movable arm

extended from the same vertical rod. A drawing of the apparatus is shown on Pl. 1.

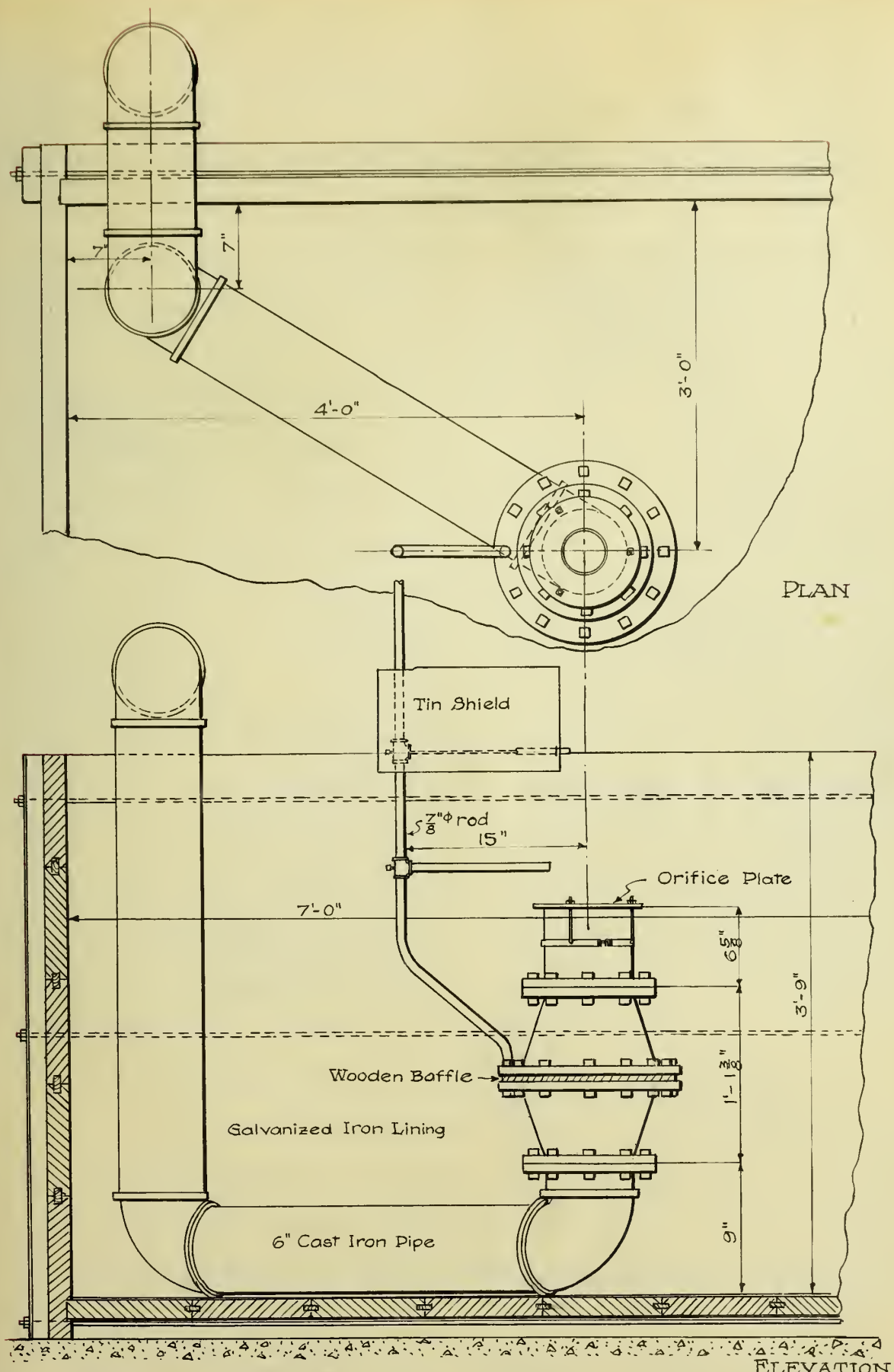
PREVIOUS EXPERIMENTS. The chief experiments that have been made with the vertical jet have been made by the United States Hydrographic Survey. Laboratory experiments have been conducted by F. E. Lawrence and P. E. Braunworth at Cornell University, by C. V. Seastone at the University of Illinois, by S. G. Cutler and R. D. Marsden in 1908 at the University of Illinois and by A. M. Korsmo and B. L. Jones in 1909 at the University of Illinois. In the tests here reported the results obtained by Jones and Korsmo have been used for comparison.

PURPOSE OF EXPERIMENTS. The tests were made with the idea of calibrating orifices on a six inch short tube, the apparatus being constructed similar to that tested by Cutler and Marsden, and by Jones and Korsmo. and also to test the accuracy of the determination of the coefficient of discharge without the necessity of measuring the discharge. The coefficients determined by direct measurement of the jet were compared with those found from actual measurement of discharge.

APPARATUS AND EXPERIMENTS. The experiments were made at the University of Illinois in the Hydraulics Laboratory. The equipment used in the experiments consisted of one Duplex Pump, capacity 2200 gallons per minute, a stand-pipe four feet in diameter and sixty feet high, a pump sump twelve feet in diameter and a measuring box fifteen by seven by three feet nine inches. The jet apparatus was located in the north-west corner of the laboratory on the second floor and in the measuring box above mentioned. The jet apparatus was connected to the stand-pipe by means of a pipe line. A valve was located next to the stand-pipe and another near

2 Inch Orifice on 6 Inch Short Tube.

Showing Tin Shield in Position.



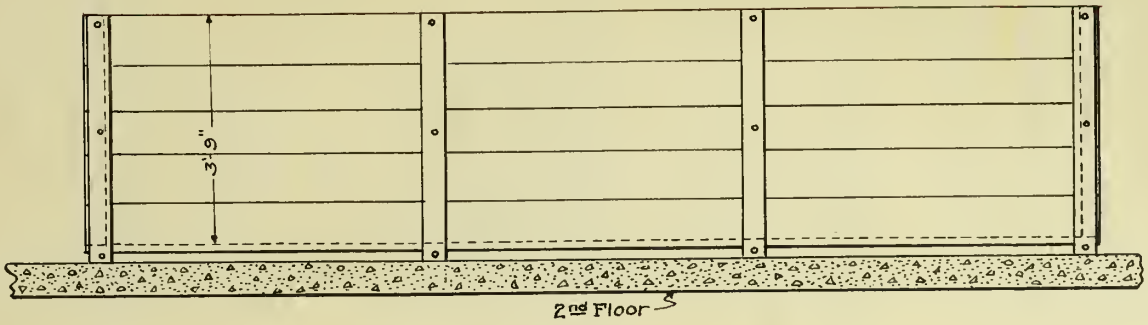
APPARATUS SHOWING 6 INCH SHORT TUBE IN USE.

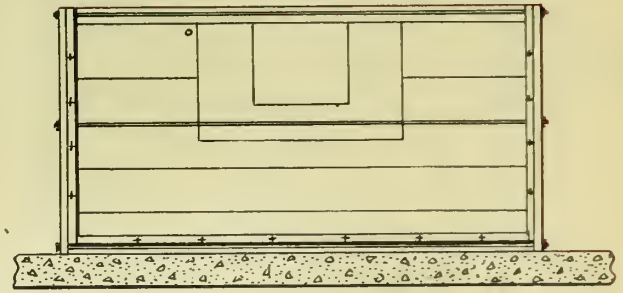
the jet by means of which the head of the jet was regulated. The water discharged from the measuring box into a pit by means of a four inch pipe in the bottom of box, thence into the sump. The water was pumped from the sump into the stand-pipe, thence through the pipe line to the jet. The level of the water in the stand-pipe could be kept at any desired head by adjusting the weight on governing lever of pump. The water level in the measuring box was measured by means of a hook gage. The head at the stand-pipe was ordinarily 45 feet.

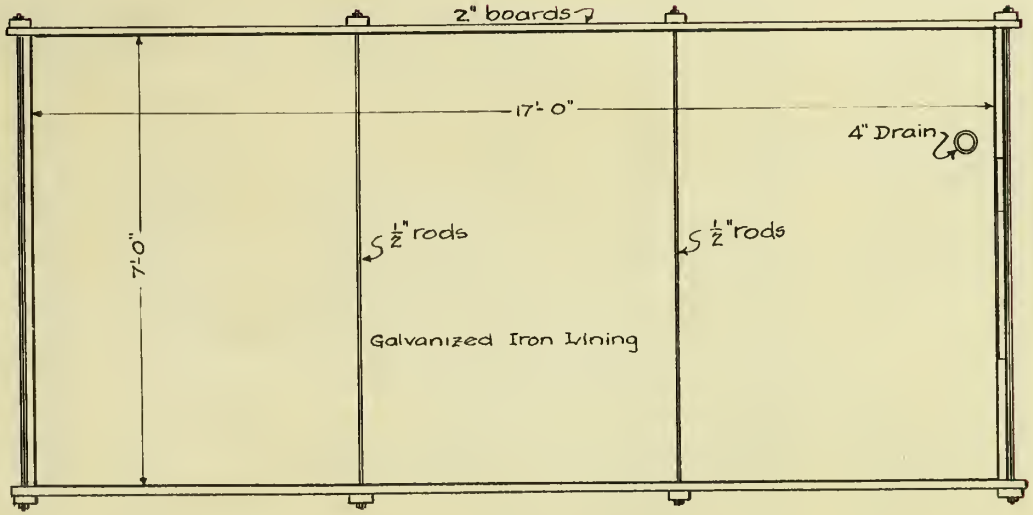
METHODS OF MEASUREMENT. In order that the discharge in cubic feet per second be accurately determined it is necessary (1) that the water flowing in a certain time be collected in a pit and measured by displacement and (2) that the time of flow into the pit must be accurately measured. The first condition was obtained by calibrating the pit using known weights of water, reading the hook gage after each known weight was discharged into the pit, and plotting a calibration curve with readings of hook gage in feet as abscissae and quantity of water reduced to cubic feet as ordinates. The calibration curve for measuring box is shown on Pl. 4. With hook gage reading before and after any discharge the quantity of water discharging into the pit can be obtained from the calibration curve.

Accurate measurement of time was secured by setting the hook gage at an initial reading and starting a stop watch when the water reached this point, then moving the gage up a foot or so and stopping the watch when the water reached the new level. A stilling box was used to keep the water as quiet as possible near the gage.

Having obtained the total discharge and time of discharge, the







MEASURING BOX

discharge in cubic feet per second was calculated and from this the actual coefficient of discharge.

The measurement of the head on the jet was made by means of sighting rods. The zero reading of the orifice was first obtained by holding a rule up from the plane of the orifice and reading the rod over the top of the rule and subtracting the length of the rule from this rod reading. The height of the jet was obtained by subtracting the zero reading of the orifice from the rod reading over the top of the jet. The sighting rods were graduated into feet, tenths and hundreths of a foot. The rod next to the observer's eye was nine feet from the jet and the other rod was three feet on the opposite side of the jet and thus any error in the height of observer's eye was decreased to one third of its real amount. Readings to .01 of a foot were thus obtained with comparative ease.

In obtaining the coefficient of discharge by direct measurement of the jet, it was necessary to take the diameter of the jet and the height of the section besides the height of the jet above the orifice.

EXPERIMENTS. Experiments were first made on a six inch tube, six inches long with various size orifices attached. Readings were taken with two, three, four and five inch orifices, the discharge being measured by displacement for each orifice. A tube twelve inches long was then used in place of the tube six inches long and the experiments repeated as above. The jets were measured in every case in order to determine the accuracy of computing the coefficient of discharge from direct measurement of the jet. Experiments were also made on a twelve inch vertical jet apparatus but the coefficients by direct measurement alone were computed as

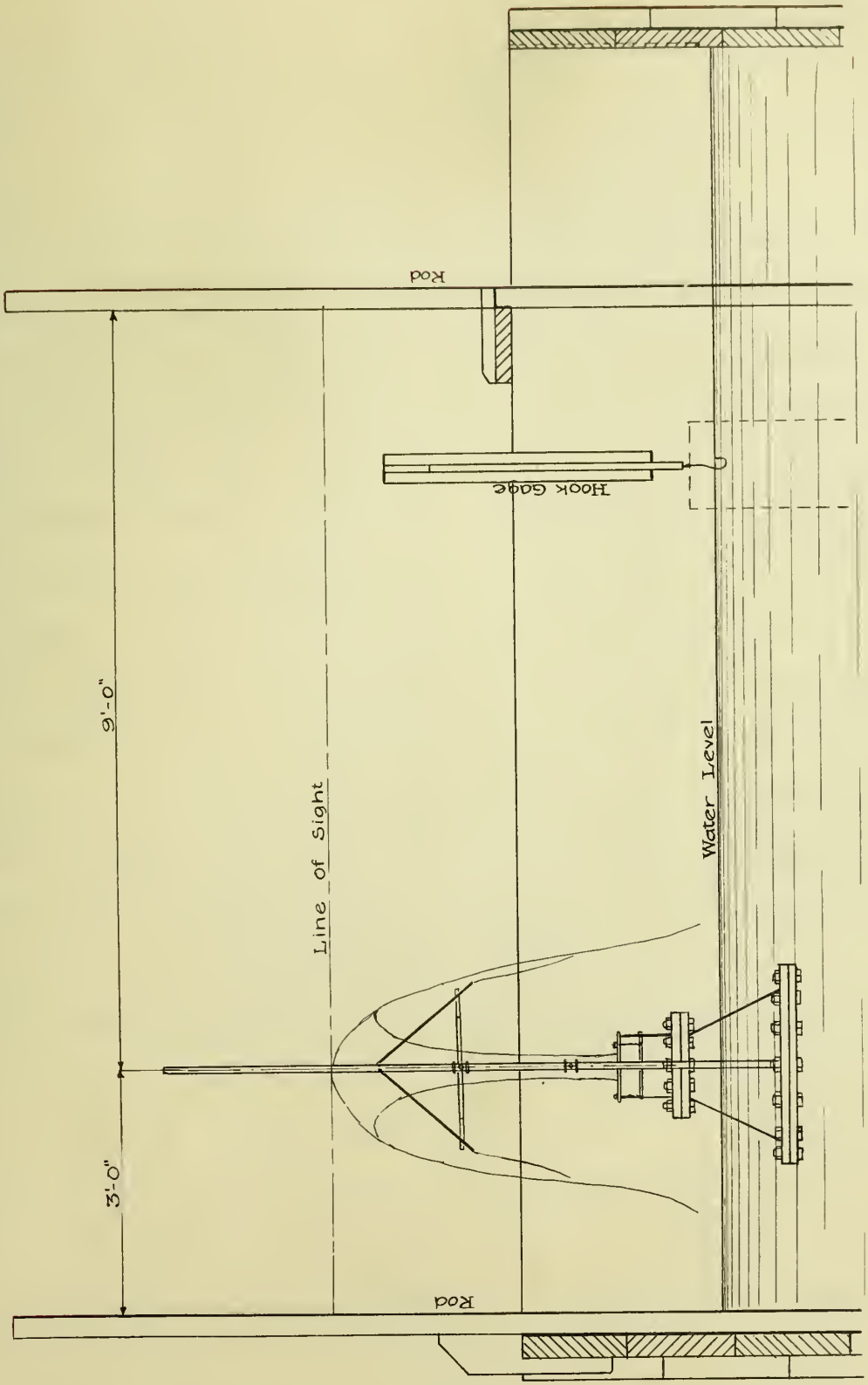


DIAGRAM SHOWING JET MEASURING APPARATUS

this size apparatus had previously been calibrated by actual measurement of the discharge by Cutler and Marsden and by Jones and Korsmo. Readings of tho head were obtained and the corresponding coefficients of discharge were taken from Jones and Korsmos' thesis. The size of orifices used on the twelve inch pipe were four, six, eight and ten inches in diameter.

All orifices excepting the five inch orifice on the six inch tube gave a smooth jet, the distribution of velocity throughout the cross-section being good. The five inch orifice gave a poor jet which was probably due to the fact that there was not enough contraction to equalize the flow.

GENERAL FORMULAE. A glance at the formulae for the flow of water through any conduit will show that two quantities are involved, (1) the cross-section area of the flowing water normal to the direction of flow and (2) the velocity of flow which in turn depends on the head producing the flow. If the velocities were constant through the cross-section the measurement of flow would be simple, but since the velocities are not constant certain coefficients peculiar to the conditions of flow have to be incorporated in the theoretical formulae.

The different methods of measuring water are: directly by weight and by volume; indirectly by weirs, vertical orifices, venturi meters, floats, current meters etc. The method most commonly used in the measurement of large quantities of water however is by means of the weir. Since the weir is the most commonly used, it will be taken as a standard of comparison for the vertical jet.

GENERAL COMPARISONS. The comparison of the relative value of these two devices must be (1) a comparison of the ease and cost

of construction of each and (2) the relative accuracy of each.

(1) To compare the construction and cost of the two involves the use which is made of them. If the water in an open channel is to be measured, the weir will be the most practical method, as it is easier to construct a weir across the channel to hold back sufficient water to give the extra drop required for the weir. Care must be taken of course to make the weir level and straight. To measure the same by a vertical jet would require the construction of a large collecting box and the necessary backing up of the water which would cost considerable, thus making the jet inpracticable. In cases where water is flowing through a closed pipe, as in public water supplies, and duty tests of pumping engines, or where water is flowing through open channels where there is plenty of fall and the water can be made to flow into a pipe as is the case in irrigation work in the Western part of the United States, the vertical jet is more easily constructed. The necessary material for constructing such an apparatus would be a short section of vertical pipe, a set of reducers, baffles to equalize the flow and an orifice plate which is secured to the top of the short tube. This method of measurement will more than likely come into use in connection with making commercial tests on pumping engines, because of its ease of building and transportation.

(2) The theoretical formula for the discharge from a rectangular weir with suppressed end contractions and no velocity of approach is

$$Q=\frac{2}{3}b\sqrt{2g}\ H^{\frac{3}{2}}$$ where

b = width of crest of weir.

g = acceleration due to gravity.

H = head on crest of weir.

3 Inch Orifice on 6 Inch Short Tube.

The theoretical formula for the discharge of a vertical jet is $Q = a\sqrt{2g}\ H^{\frac{1}{2}}$, being derived from $Q = av$ and $v = \sqrt{2gh}$ where

a = area of orifice.

g = acceleration due to gravity.

H = head on orifice or height of jet.

It is readily seen that when any variable quantity is raised to a higher power the resulting error is modified. Let r be probable error of measurement in H, and R the corresponding error in Q. For the weir

$$Q_1 = \frac{2}{3}b\sqrt{2g}\ H_1^{\frac{3}{2}}$$

$$(1) \qquad Q = KH_1^{\frac{3}{2}}$$

$$Q_1 \pm R_1 = K(H_1 \pm r_1)^{\frac{3}{2}}$$

$$= K_1\left[H\left(1 \pm \frac{r_1}{H_1}\right)\right]^{\frac{3}{2}}$$

$$(2) \quad Q_1 \pm R_1 = KH_1^{\frac{3}{2}}\left(1 \pm \frac{3}{2}\left(\frac{r_1}{H_1}\right) \pm \frac{3}{8}\left(\frac{r_1}{H_1}\right)^2 \pm \text{-------etc.}\right)$$

$$(1) \qquad Q = KH_1^{\frac{3}{2}}$$

Subtracting 1 from 2

$$\pm R_1 = KH_1^{\frac{3}{2}}\left(\pm\frac{3}{2}\left(\frac{r_1}{H_1}\right) \pm \frac{3}{8}\left(\frac{r_1}{H_1}\right)^2 \pm \text{------- etc.}\right)$$

Neglecting all but first power of $\left(\frac{r_1}{H_1}\right)$

$$\frac{R_1}{Q_1} = \pm\frac{3}{2}\left(\frac{r_1}{H_1}\right)$$

For the jet

$$Q_2 = a\sqrt{2g}\ H_2^{\frac{1}{2}}$$

$$(3) \qquad Q_2 = KH_2^{\frac{1}{2}}$$

$$Q_2 \pm R_2 = K(H_2 \pm r_2)^{\frac{1}{2}}$$

$$= K\left[H_2\left(1 \pm \left(\frac{r_2}{H_2}\right)\right)\right]^{\frac{1}{2}}$$

$$(4) \quad Q_2 \pm R_2 = KH_2^{\frac{1}{2}}\left(1 \pm \frac{1}{2}\left(\frac{r_2}{H_2}\right) \text{---------etc.}\right)$$

$$(3) \qquad Q_2 = KH_2^{\frac{1}{2}}$$

Subtracting 3 from 4

$$\pm R_2 = KH_2^{\frac{1}{2}}\left(1 \pm \frac{1}{2}\left(\frac{r_2}{H_2}\right) \pm \text{-------etc.}\right)$$

Neglecting all but first power of $(\frac{r_2}{H_2})$

$$\pm\frac{R_2}{Q_2} = \pm\frac{1}{2}\left(\frac{r_2}{H_2}\right)$$

A convenient example of the above is as follows:-An 8 inch vertical jet under a head of 4.25 feet will discharge practically the samo as a 3 foot contracted weir under a head of .520 feet as determined by experiment.

Then $Q_1 = Q_2$, $H_1 = .520$, $H_2 = 4.25$

and $\frac{R_1}{Q_1} \pm \frac{R_2}{Q_2} = \frac{3}{2}\left(\frac{r_1}{H_1}\right) \pm \frac{1}{2}\left(\frac{r_2}{H_2}\right)$

$$\frac{R_1}{R_2} = 3\frac{r_1 H_2}{r_2 H_1} = 3\frac{4.25}{.520}\frac{r_1}{r_2} = 24.5\,\frac{r_1}{r_2}$$

The head on jet can be read to .01 of a foot and the head on weir to .001 of a foot. Then $10r_1 = r_2$

$$\frac{R_1}{R_2} = 24.5\,\frac{r_1}{r_2} = 24.5 \times \frac{1}{10} = 2.45$$

which shows the jet to be approximately two and a half times as sensitive as the weir. Under low heads the jet is more stable and can be read to .005 of a foot while the weir is inaccurate under the same discharge on account of surface tension etc, and the jet would then be about five times as sensitive as the weir. When the vertical jet has been carefully calibrated it will therefore give more accurate results than a weir. Another advantage the vertical jet has over a weir for some kinds of work is that the vertical jet measures the quantity flowing in the pipe at the instant while with a weir a long time must elapse after a change in rate of discharge is made before readings can be taken.

DISCUSSION OF RESULTS AND CONCLUSIONS.

COEFFICIENTS. The coefficients by displacement were computed from the formula $Q = ca\sqrt{2gH}$ or $c = \frac{Q}{a\sqrt{2gH}}$ where

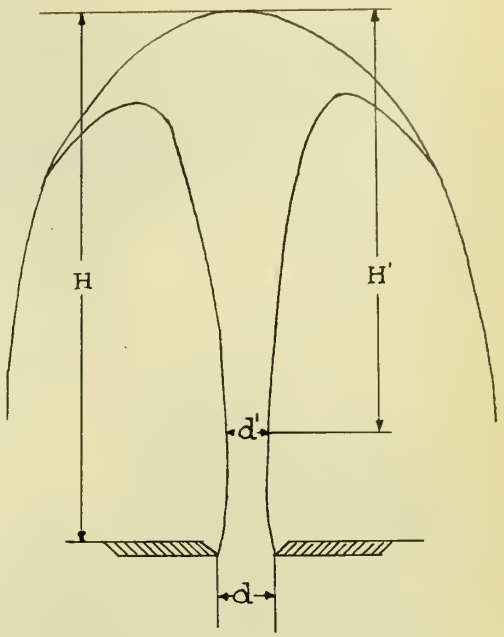
Q = the water discharged in cubic feet per second.

a = area of orifice in square feet.

g = acceleration due to gravity.

H = head on jet in feet.

The coefficients by direct measurement were computed from the following theory. If d' be the diameter of the jet at any point above the contracted section and h' the head of the jet at that point, then $Q' = a'\sqrt{2gH'} = \frac{\pi d'^2}{4}\sqrt{2gH'}$ if there was no friction due to the air and if the velocity was uniform in all parts of the cross-section. In these experiments the friction of the air was neglected. If d be the diameter of the orifice and H the head of the jet on the orifice $Q = ca\sqrt{2gH} = \frac{c\pi d^2}{4}\sqrt{2gH}$. Since the quantity flowing is constant $Q' = Q$ and



$$\frac{\pi d'^2}{4}\sqrt{2gH'} = \frac{c\pi d^2}{4}\sqrt{2gH}$$

$$c = \frac{\frac{\pi d'^2}{4}\sqrt{2gH'}}{\frac{\pi d^2}{4}\sqrt{2gH}} = \frac{d'^2\sqrt{H'}}{d^2\sqrt{H}}$$

The coefficient curves are plotted for the jet condition only. The weir condition on a vertical tube is explained in Cutler and Marsden's Thesis, but as it is the aim of this thesis to investigate the accuracy of determining coefficients of discharge by direct measurement, the explanation will not be repeated because the method of direct measurement cannot be applied to the weir condition.

Jones and Korsmo state in their thesis that the coefficient curves are not straight lines but are slightly concave downward, the same being more apparent in the case of the smaller orifices. Owing to the fact that the writers of this thesis were unable to

6 Inch Orifice on 12 Inch Short Tube.

take a large range of heads because of the necessity of getting under the jet to measure the diameter, it was found that the coefficient curve was a straight line. The discharge curve is a parabola. Variations in the coefficients slightly change the form of curve but it is very nearly parabolic.

RESULTS OBTAINED AND RECOMMENDATIONS. Some idea of the results may be obtained from the curves of discharge and discharge coefficients. It was found that the coefficients of discharge could be measured quite accurately by direct measurement of the jet for the small orifices but owing to the irregularity of the jet with the eight and ten inch orifices, the coefficients by direct measurement checked only within about ten percent of those obtained by Jones and Korsmo by comparison with a weir. There is a tendency to overestimate the diameter of the jet when the jet is unsteady which causes the calculated coefficient of discharge to be too large. To get the best results as small an orifice as would give the discharge required should be used since the smaller orifices give better distribution, it being impracticable to use orifices larger than ten inches in diameter because of this unequal distribution.

The jet should be used with the heads high enough so that the diameter can be measured. Also the jet should not be used above a certain maximum head because of difficulty of measurement, due to breaking up of jet. The heads recommended are,

Size of Orifice	3"	4"	6"	8"	10"
Size of Tube	12"	12"	12"	12"	12"
Minimum Head	1.0'	1.2'	1.4'	1.4'	1.6'
Maximum Head	6.0'	5.0'	4.5'	4.0'	3.0'

Size of Orifice	2"	3"	4"	5"
Size of tube	6"	6"	6"	6"
Minimum Head	1.0'	1.4'	1.8'	2.0'
Maximum Head	6.0'	6.0'	5.0'	4.5'

Heads near minimum are recommended as these give steadier conditions of flow and are more easily read. The measurement of the diameter should be taken at the smallest section of the jet or just above that point. If the measurements are taken more than six inches above the contracted section the coefficients will be inaccurate as the jet will be very irregular. The throttling valve should be placed near the jet and should be throttled at this point almost entirely for this serves to prevent the pressure fluctuations in the supply pipe. The orifice plate should be firmly bolted against the top of the short tube because if it is not, water will be forced out at this point and this will greatly affect the discharge and the coefficient of discharge.

TABLE NO. I

2 Inch Orifice on 6 Inch Short Tube.

Displacement.								Direct Measurement.				
Pit Gage		Time	Disch	Jet zero=.654				Jet			Disch.	Coef
Init. Ft.	Final Ft.	Sec.	Cu.ft. sec.	Rod Ft.	Aver. Ft.	Head Ft.	Coef	Diam In.	Rod Ft.	Head Ft.	Cu.ft sec.	
0.0	1.0	765	0.136	2.24			0.621	1.55	0.737	1.487	.129	0.590
				2.23				1.60	0.895	1.329	.129	0.590
				2.22				1.64	0.978	1.246	.131	0.597
				2.21				1.68	1.041	1.183	.134	0.614
				2.22	2.22	1.570						
0.0	1.0	653	0.159	2.92			0.612	1.55	0.737	2.137	.154	0.593
				2.90				1.59	0.895	1.979	.156	0.600
				2.88				1.64	0.987	1.887	.162	0.623
				2.85				1.70	1.100	1.774	.168	0.647
				2.82	2.87	2.22						
0.0	1.0	578	0.180	3.45			0.613	1.55	0.737	2.713	.173	0.591
				3.43				1.59	0.895	2.555	.177	0.603
				3.42				1.66	1.075	2.375	.185	0.631
				3.42				1.72	1.116	2.334	.198	0.676
				3.43	3.45	2.796						
0.0	1.0	526	0.198	4.10			0.608	1.55	0.737	3.373	.193	0.592
				4.11				1.59	0.895	3.215	.198	0.608
				4.12				1.66	0.991	3.119	.213	0.652
				4.11				1.70	1.000	3.060	.221	0.678
				4.11	4.11	3.456						

TABLE NO.II

3 Inch Orifice on 6 Inch Short Tube.

Displacement.								Direct Measurement.				
Pit Gage.		Time	Disch.	Jet zero=.654				Jet			Disch.	Coef
Init, Ft	Final Ft	Sec.	Cu.Ft Sec.	Rod Ft.	Aver. Ft.	Head Ft.	Coef	Diam In.	Rod Ft,	Head Ft.	Cu.Ft Sec.	
0.0	1.5	483	0.323	2.32			0.634	2.42	0.737	1.595	.323	0.634
				2.33				2.52	0.895	1.437	.333	0.655
				2.32				2.60	1.008	1.324	.341	0.671
				2.34				2.69	1.083	1.249	.353	0.694
				2.35	2.33	1.678						
0.0	1.5	430	0.364	2.75			0.640	2.42	0.737	2.013	.364	0.640
				2.76				2.46	0.895	1.855	.362	0.636
				2.74				2.52	0.991	1.759	.369	0.649
				2.76				2.58	1.058	1.692	.378	0.665
				2.74	2.75	2.096						
0.0	1.5	397	0.394	3.17			0.632	2.42	0.737	2.423	.398	0.639
				3.18				2.47	0.895	2.265	.401	0.644
				3.16				2.52	1.000	2.160	.408	0.655
				3.15				2.58	1.100	2.060	.408	0.655
				3.14	3.16	2.506						
0.0	1.5	364	0.429	3.80			0.628	2.42	0.737	2.933	.440	0.645
				3.62				2.47	0.895	2.775	.445	0.652
				3.60				2.54	0.983	2.687	.462	0.662
				3.67				2.57	1.025	2.645	.471	0.688
				3.66	3.67	3.016						
0.0	1.5	334	0.468	4.31			0.626	2.42	0.737	3.555	.485	0.647
				4.32				2.46	0.895	3.397	.489	0.652
				4.30				2.51	0.956	3.336	.490	0.653
				4.26				2.55	1.025	3.276	.513	0.685
				4.27	4.29	3.638						

TABLE NO. III

4 Inch Orifice on 6 Inch Short Tube.

Displacement.								Direct Measurement.				
Pit Gage		Time	Disch.	Jet zero=.654				Jet			Disch.	Coef.
Init. Ft.	Final Ft.	Sec.	Cu.ft. sec.	Rod Ft.	Aver. Ft.	Head Ft.	Coef.	Diam. In.	Rod Ft.	Head Ft.	Cu.ft. sec.	
0.0	1.5	265	0.592	2.32			0.658	3.42	0.737	1.563	0.642	0.714
				2.28				3.46	0.895	1.405	.622	0.691
				2.29				3.49	0.958	1.342	.618	0.689
				2.31				3.52	1.000	1.300	.619	0.689
				2.30	2.30	1.646						
0.0	1.5	233	0.672	2.30			0.658	3.41	0.737	1.933	0.706	0.692
				2.75				3.43	0.895	1.875	.704	0.688
				2.83				3.47	0.958	1.812	.707	0.692
				2.78				3.51	1.029	1.741	.712	0.697
				2.79	2.77	2.116						
0.0	1.5	215	0.728	3.25			0.655	3.40	0.737	2.441	0.790	0.708
				3.18				3.41	0.895	2.283	.772	0.694
				3.20				3.43	0.962	2.216	.765	0.687
				3.14				3.47	1.016	2.162	.774	0.695
				3.12	3.18	2.524						
0.0	1.5	199	0.786	3.55			0.658	3.39	0.737	2.827	0.848	0.707
				3.57				3.40	0.895	2.669	.827	0.692
				3.56				3.42	0.975	2.589	.828	0.692
				3.55				3.47	1.054	2.510	.832	0.695
				3.59	3.56	2.910						

TABLE NO.IV

5 Inch Orifice on 6 Inch Short Tube.

Displacement.								Direct Measurement.				
Pit Gage		Time	Disch.	Jet zero=.654				Jet.			Disch.	Coef.
Init Ft.	Final Ft.	Sec.	Cu.ft. sec.	Rod Ft.	Aver. Ft.	Head Ft,	Coef.	Diam In.	Rod Ft.	Head Ft.	Cu.ft. sec.	
0.3	1.6	184	0.905	2.09			0.652	4.36	0.737	1.319	0.965	0.695
				2.07				4.40	0.895	1.161	0.915	0.660
				2.04				4.46	0.958	1.098	0.917	0.661
				2.05				4.62	1.037	1.019	0.952	0.686
				2.03	2.06	1.402						
0.0	1.9	178	1.112	2.70			0.671	4.35	0.737	1.911	1.148	0.693
				2.65				4.40	0.895	1.753	1.120	0.675
				2.63				4.48	1.008	1.640	1.128	0.681
				2.62								
				2.64	2.65	1.994						
0.1	1.8	142	1.319	3.66			0.656	4.36	0.737	2.887	1.387	0.690
				3.67				4.40	0.895	2.729	1.397	0.694
				3.60				4.45	1.012	2.612	1.402	0.697
				3.61								
				3.58	3.63	2.970						

TABLE NO. V

3 Inch Orifice on 6 Inch Long Tube.

Displacement.								Direct Measurement.				
Pit Gage		Time	Disch.	Jet zero= 1.167				Jet			Disch.	Coef.
Init. Ft.	Final Ft.	Sec.	Cu.ft sec.	Rod Ft.	Aver. Ft.	Head Ft.	Coef	Diam. In.	Rod Ft.	Head Ft.	Cu.ft. sec.	
0.2	1.2	426	0.245	2.15			0.632	2.43	1.258	.882	0.250	0.644
				2.14				2.47	1.304	.836	0.247	0.636
				2.13				2.50	1.358	.782	0.242	0.624
				2.15				2.53	1.400	.740	0.242	0.624
				2.13	2.14	0.973						
0.1	1.1	331	0.315	2.74			0.639	2.42	1.258	1.482	0.313	0.634
				2.74				2.44	1.300	1.440	0.313	0.634
				2.73				2.48	1.408	1.332	0.312	0.632
				2.75				2.51	1.500	1.240	0.319	0.647
				2.74	2.74	1.573		2.57	1.583	1.157	0.312	0.632
0.1	1.5	387	0.367	3.45			0.685	2.42	1.258	2.220	0.383	0.642
				3.47				2.43	1.350	2.128	0.380	0.636
				3.48				2.46	1.458	2.020	0.377	0.632
				3.49				2.51	1.541	1.937	0.383	0.641
				3.50	3.48	2.311						
0.1	1.5	339	0.430	4.17			0.635	2.42	1.258	2.884	0.437	0.644
				4.15				2.42	1.308	2.834	0.433	0.640
				4.14				2.43	1.425	2.717	0.427	0.630
				4.13				2.46	1.529	2.613	0.429	0.634
				4.12	4.14	2.975		2.50	1.625	2.517	0.433	0.640
0.1	1.6	327	0.478	5.01			0.621	2.42	1.341	3.659	0.492	0.639
				4.99				2.42	1.458	3.542	0.484	0.629
				5.00				2.46	1.583	3.417	0.490	0.637
				5.01				2.51	1.683	3.317	0.498	0.635
				4.99	5.00	3.833						

TABLE NO.VI

4 Inch Orifice on 6 Inch Long Tube.

Displacement.								Direct Measurement.				
Pit Gage		Time	Disch.	Jet zero=1.167				Jet			Disch.	Coef.
Init. Ft.	Final Ft.	Sec.	Cu.ft. sec.	Rod Ft.	Aver. Ft.	Head Ft.	Coef.	Diam. In.	Rod Ft.	Head Ft,	Cu.ft sec.	
0.1	1.3	249	0.503	2.36			0.658	3.40	1.258	1.100	0.530	0.692
				2.35				3.41	1.300	1.008	0.512	0.670
				2.36				3.44	1.416	0.942	0.503	0.658
				2.37				3.50	1.458	0.900	0.508	0.664
				2.35	2.36	1.191						
0.1	1.6	266	0.588	2.66			0.687	3.40	1.316	1.340	0.586	0.684
				2.65				3.41	1.416	1.240	0.567	0.662
				2.66				3.46	1.541	1.115	0.555	0.649
				2.66				3.50	1.641	1.015	0.543	0.635
				2.65	2.66	1.489						
0.2	1.8	263	0.634	3.12			0.648	3.40	1.350	1.754	0.670	0.685
				3.11				3.42	1.475	1.629	0.634	0.648
				3.10				3.46	1.583	1.521	0.646	0.662
				3.09				3.52	1.666	1.438	0.652	0.667
				3.10	3.10	1.937						
0.2	1.8	225	0.740	3.78			0.652	3.40	1.425	2.361	0.778	0.685
				3.80				3.40	1.558	2.228	0.765	0.675
				3.79				3.42	1.658	2.128	0.747	0.658
				3.77				3.49	1.766	2.020	0.757	0.667
				3.79	3.79	2.619						
0.2	1.8	215	0.775	4.08			0.648	3.39	1.458	2.610	0.812	0.679
				4.10				3.40	1.541	2.527	0.805	0.672
				4.05				3.44	1.708	2.360	0.796	0.665
				4.07								
				4.04	407	2.901						

TABLE NO. VII

4 Inch Orifice on 12 Inch Short Tube.

Head	Diam.	Head on Diam.	Coef. by Displ.	Disch.	Coef. Direct Meas.
Ft.	In.	Ft.		cu.ft. sec.	
1.50	3.24	1.333	0.594	0.506	0.619
	3.26	1.290			0.615
	3.31	1.250			0.624
	3.40	1.167			0.635
1.90	3.24	1.733	0.585	0.567	0.625
	3.25	1.690			0.624
	3.28	1.650			0.626
	3.36	1.597			0.645
2.57	3.22	2.403	0.600	0.670	0.625
	3.24	2.360			0.630
	3.24	2.320			0.625
	3.29	2.337			0.631
3.07	3.20	2.903	0.603	0.737	0.625
	3.20	2.860			0.620
	3.22	2.820			0.620
	3.27	2.737			0.632

TABLE NO. VIII

6 Inch Orifice on 12 Inch Short Tube.

Head	Diam.	Head on Diam.	Coef. by Displ.	Disch.	Coef. Direct Meas.
Ft.	In.	Ft.		cu.ft. sec.	
1.40	4.90	1.233	0.612	1.130	0.625
	4.92	1.190			0.623
	4.96	1.150			0.622
	5.03	1.076			
2.05	4.94	1.883	0.610	1.355	0.650
	4.95	1.840			0.641
	4.97	1.800			0.640
	4.94	1.176			0.618
2.60	4.85	2.350	0.614	1.545	0.620
	4.88	2.266			0.617
	4.97	2.184			0.628
2.90	4.84	2.650	0.614	1.678	0.618
	4.88	2.566			0.623
	4.94	2.484			0.620

TABLE NO. IX

8 Inch Orifice on 12 Inch Short Tube.

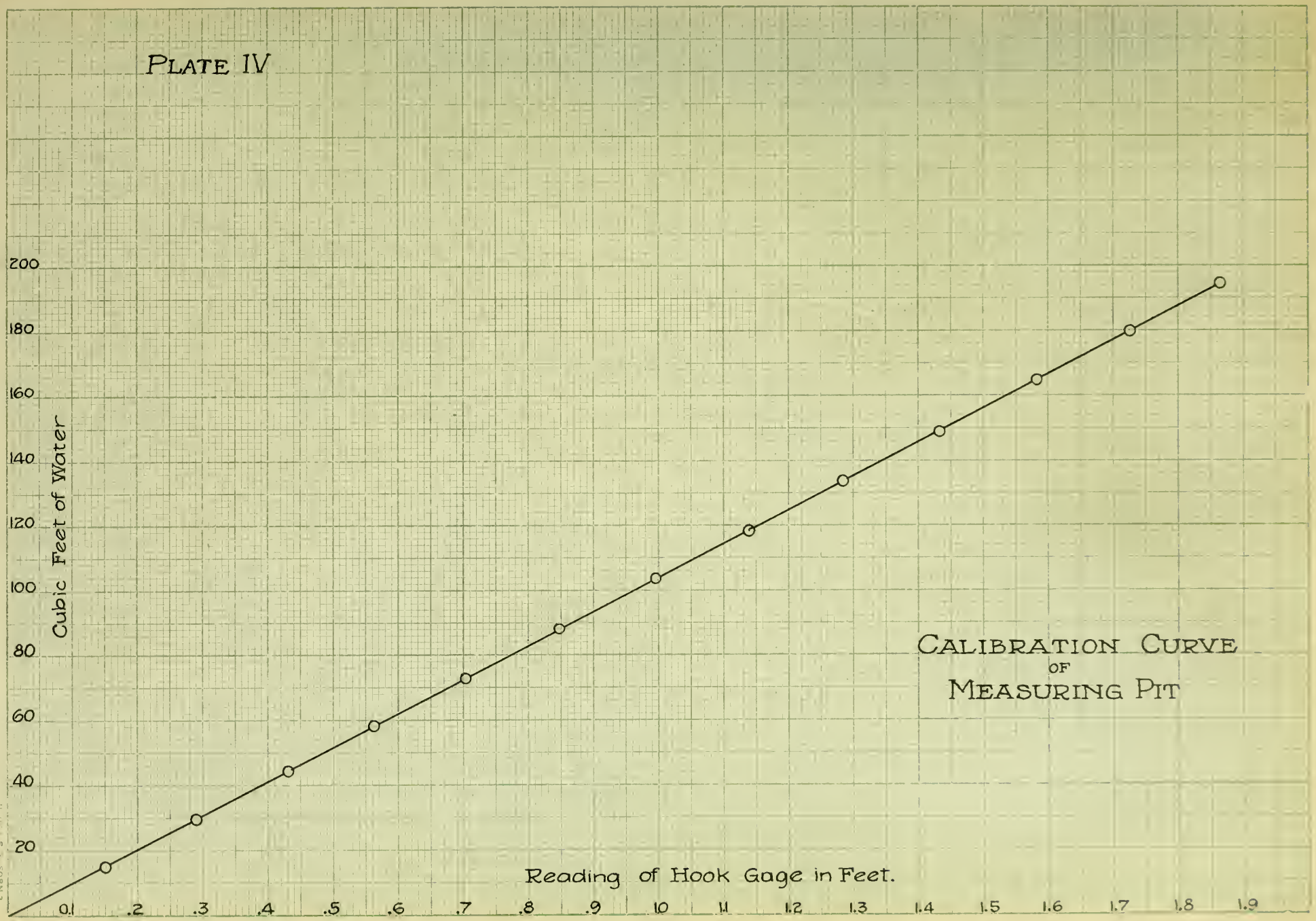
Head	Diam.	Head on Diam.	Coef. by Displ.	Disch.	Coef. Direct Meas.
Ft.	In.	Ft,		cu,ft. sec.	
1.36	7.12	1.193	0.620	1.996	0.745
	7.18	1.150			0.743
	7.22	1.110			0.702
1.67	7.05	1.503	0.636	2.318	0.721
	7.08	1.460			0.714
	6.96	1.420			0.718
	6.98	1.331			0.702
2.25	6.91	2.083	0.634	2.560	0.724
	6.92	2.040			0.707
	6.93	2.000			0.703
	6.94	1.917			0.691
2.79	6.80	2.623	0.627	2.925	0.702
	6.81	2.580			0.700
	6.82	2.540			0.695
	6.83	2.453			0.688
3.30	6.80	3.133	0.650	3.320	0.705
	6.80	3.090			0.702
	6.81	3.050			0.698
	6.82	2.967			0.692

TABLE NO. X

10 Inch Orifice on 12 Inch Short Tube.

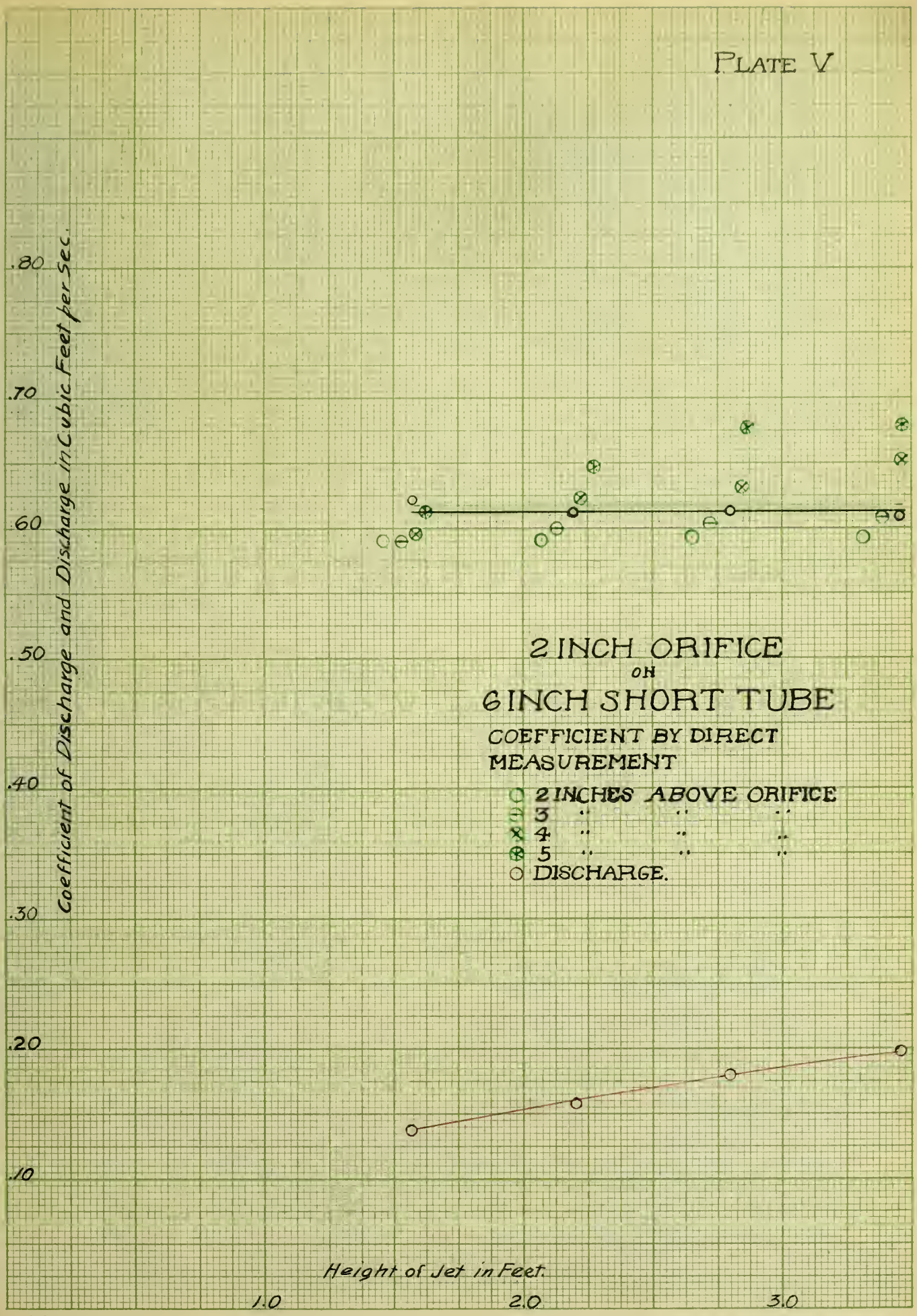
Head	Diam.	Head on Diam.	Coef. by Displ.	Disch.	Coef. Direct Meas.
Ft.	In.	Ft.		cu. ft. sec.	
1.63	8.98	1.463	0.694	3.870	0.765
	9.06	1.380			0.756
1.96	9.01	1.750	0.693	4.250	0.765
	9.04	1.710			0.765
	9.08	1.627			0.750
2.34	8.96	2.163	0.689	4.61	0.772
	8.97	2.130			0.770
	8.98	2.090			0.762
	9.02	2.007			0.752

PLATE IV



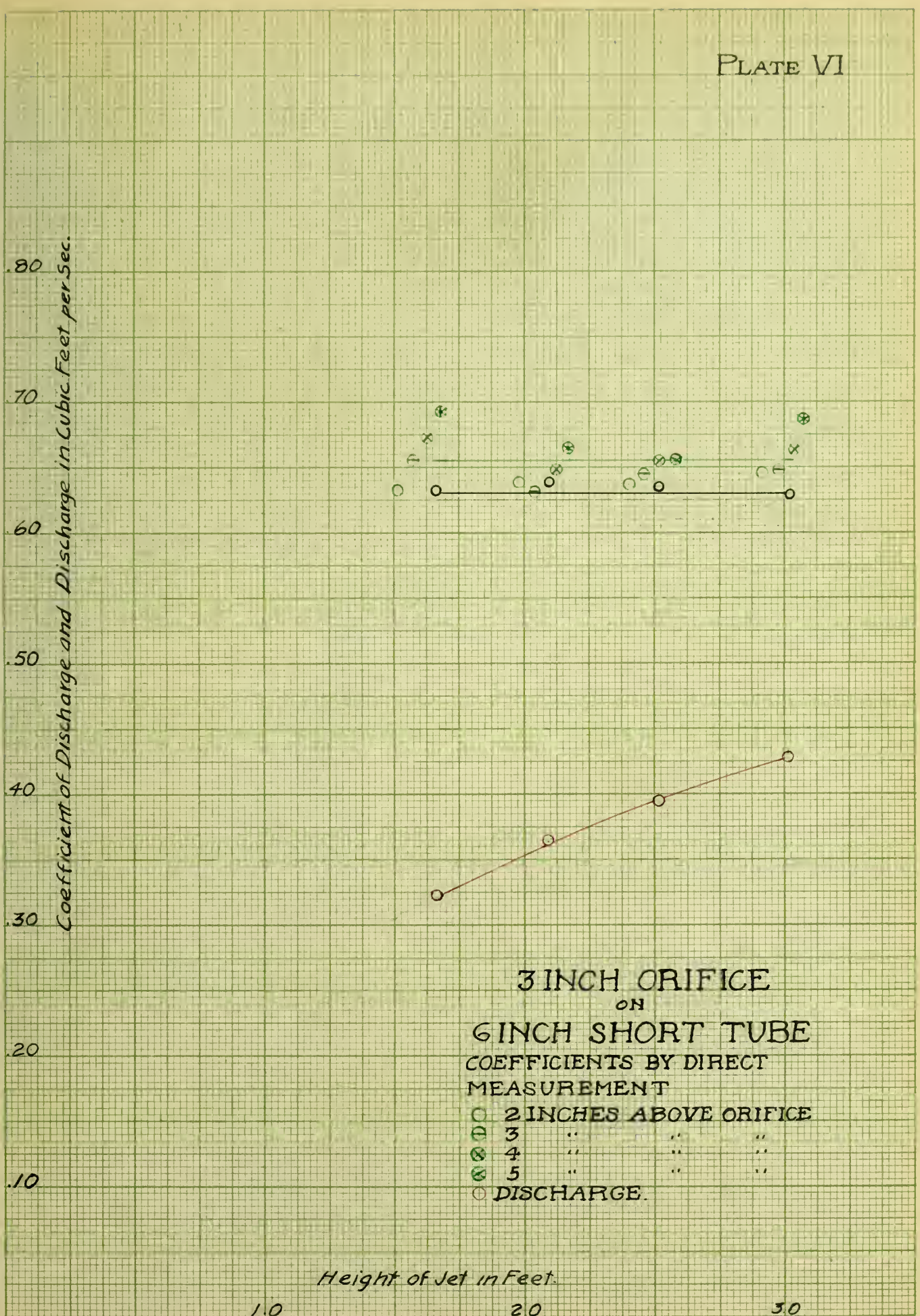
CALIBRATION CURVE
OF
MEASURING PIT

PLATE V



NO 346

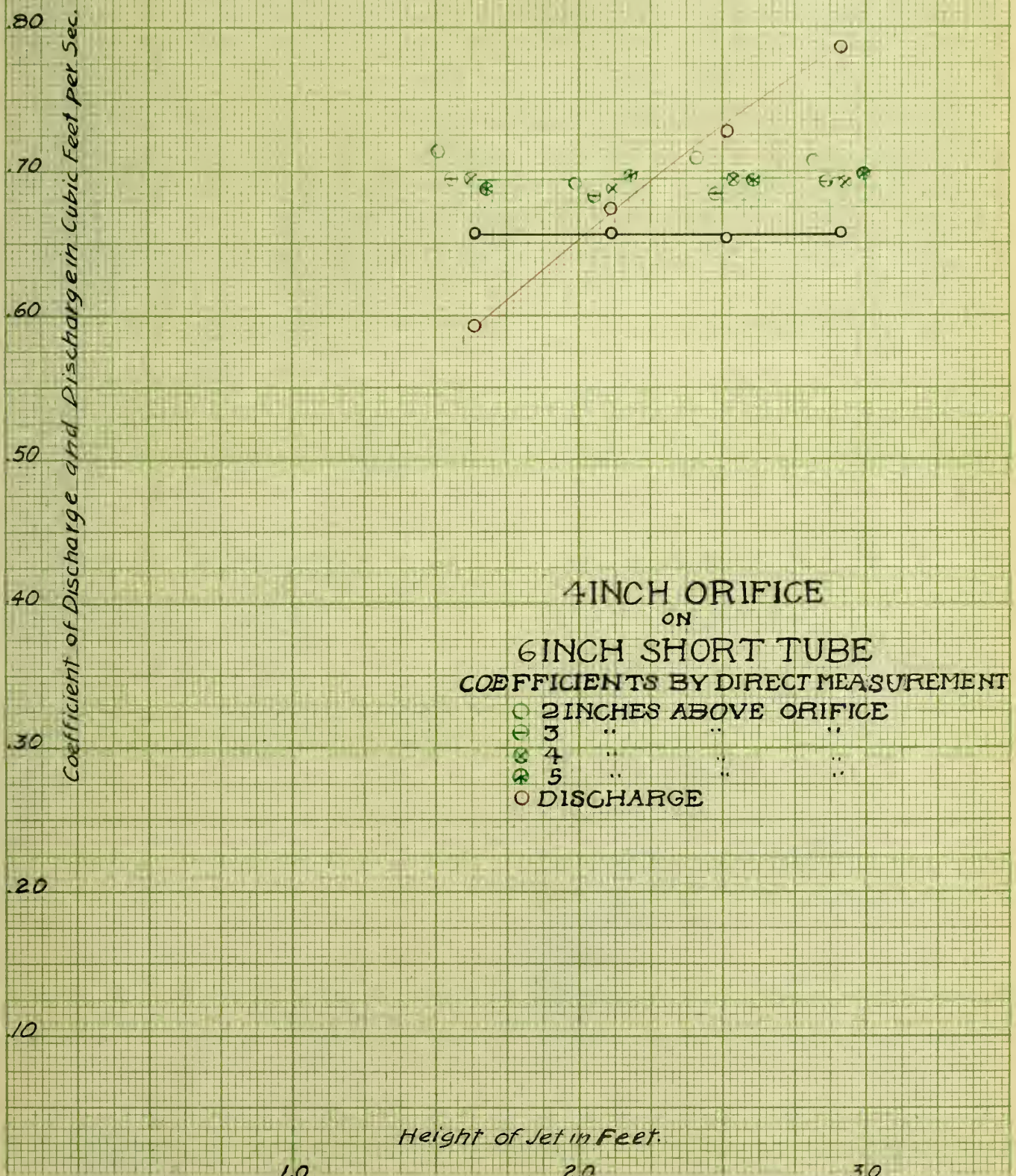
PLATE VI



3 INCH ORIFICE
ON
6 INCH SHORT TUBE
COEFFICIENTS BY DIRECT MEASUREMENT
○ 2 INCHES ABOVE ORIFICE
⊡ 3 " " "
⊗ 4 " " "
⊗ 5 " " "
○ DISCHARGE.

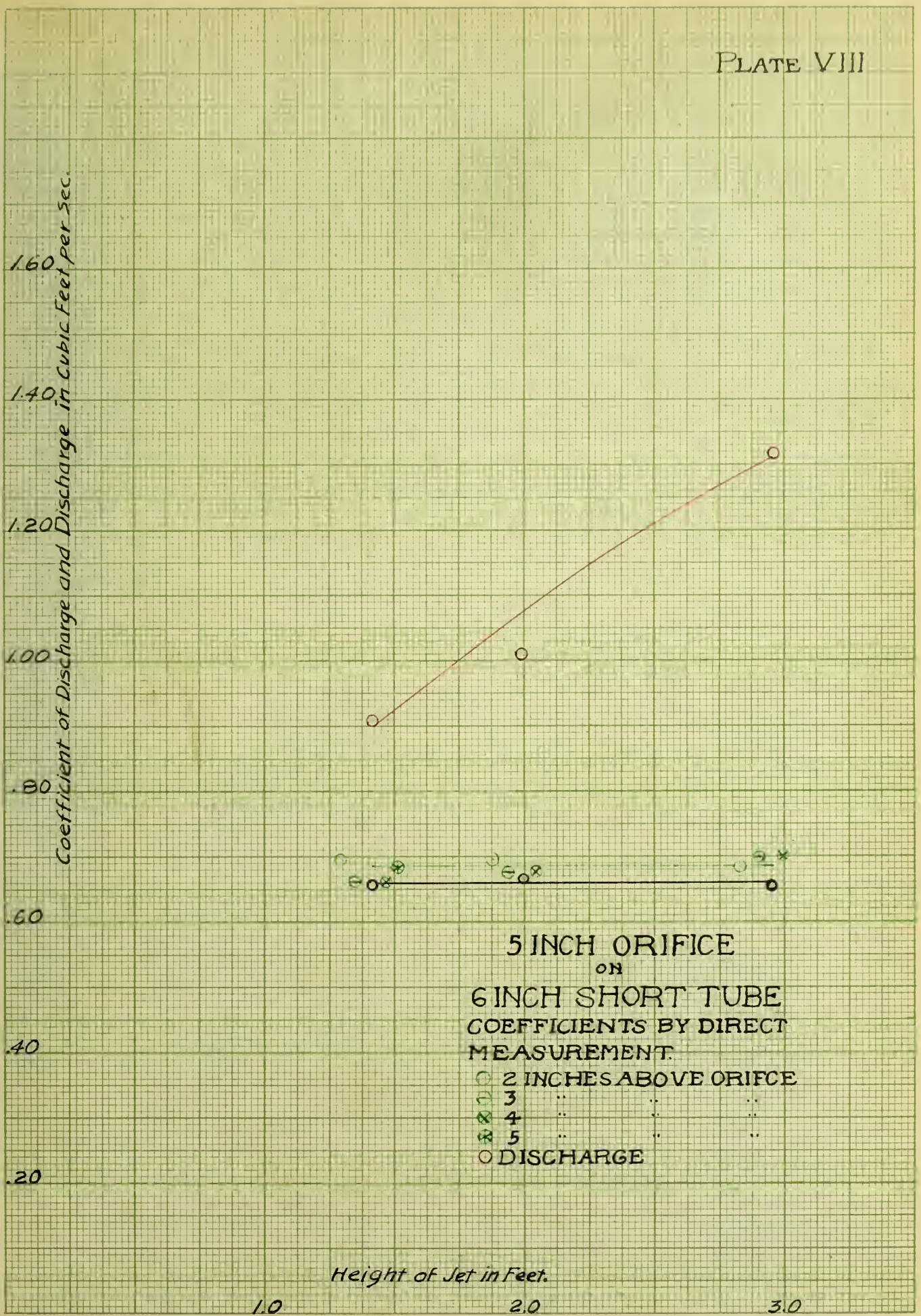
NO 346

PLATE VII



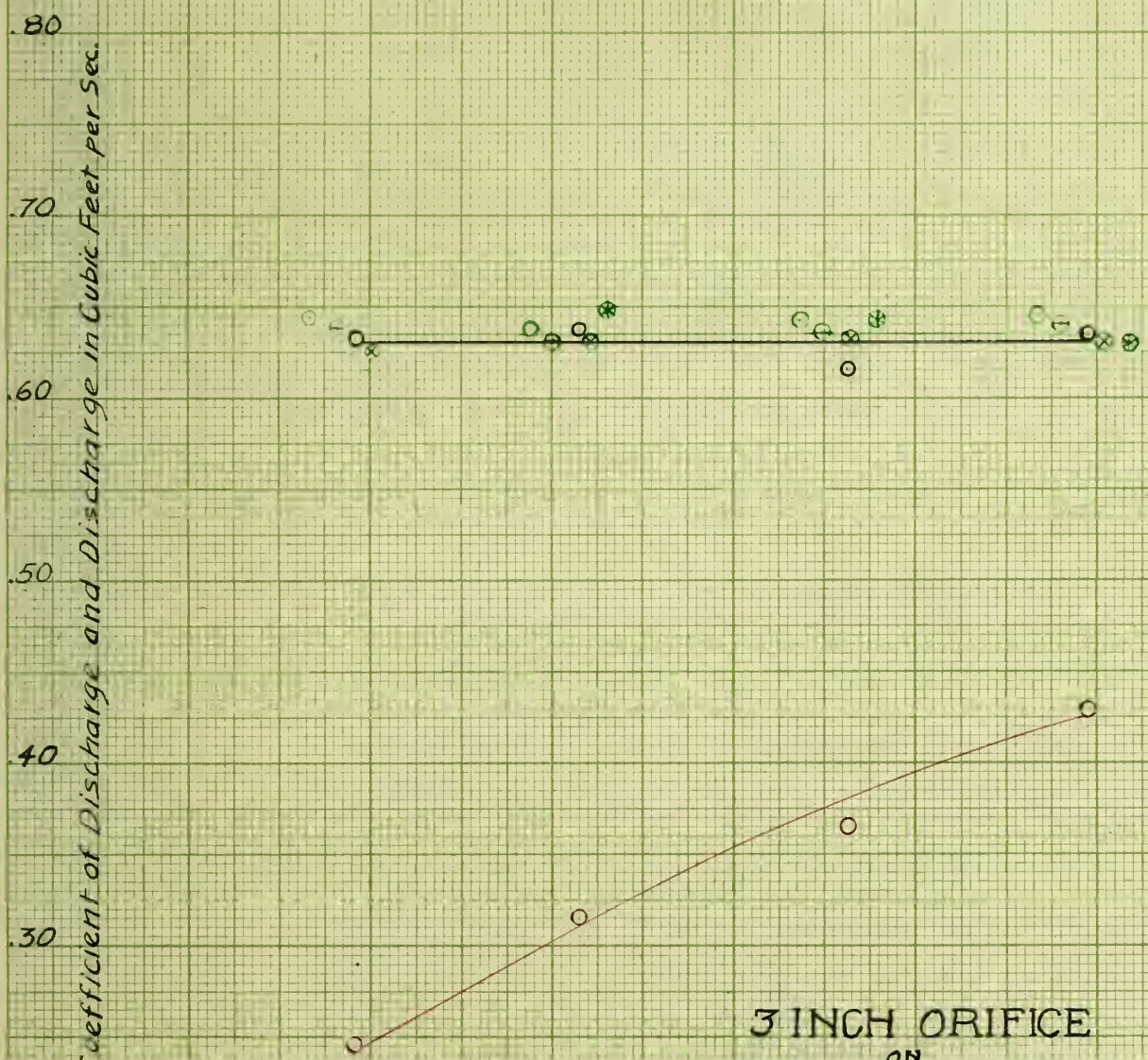
NO 346

PLATE VIII



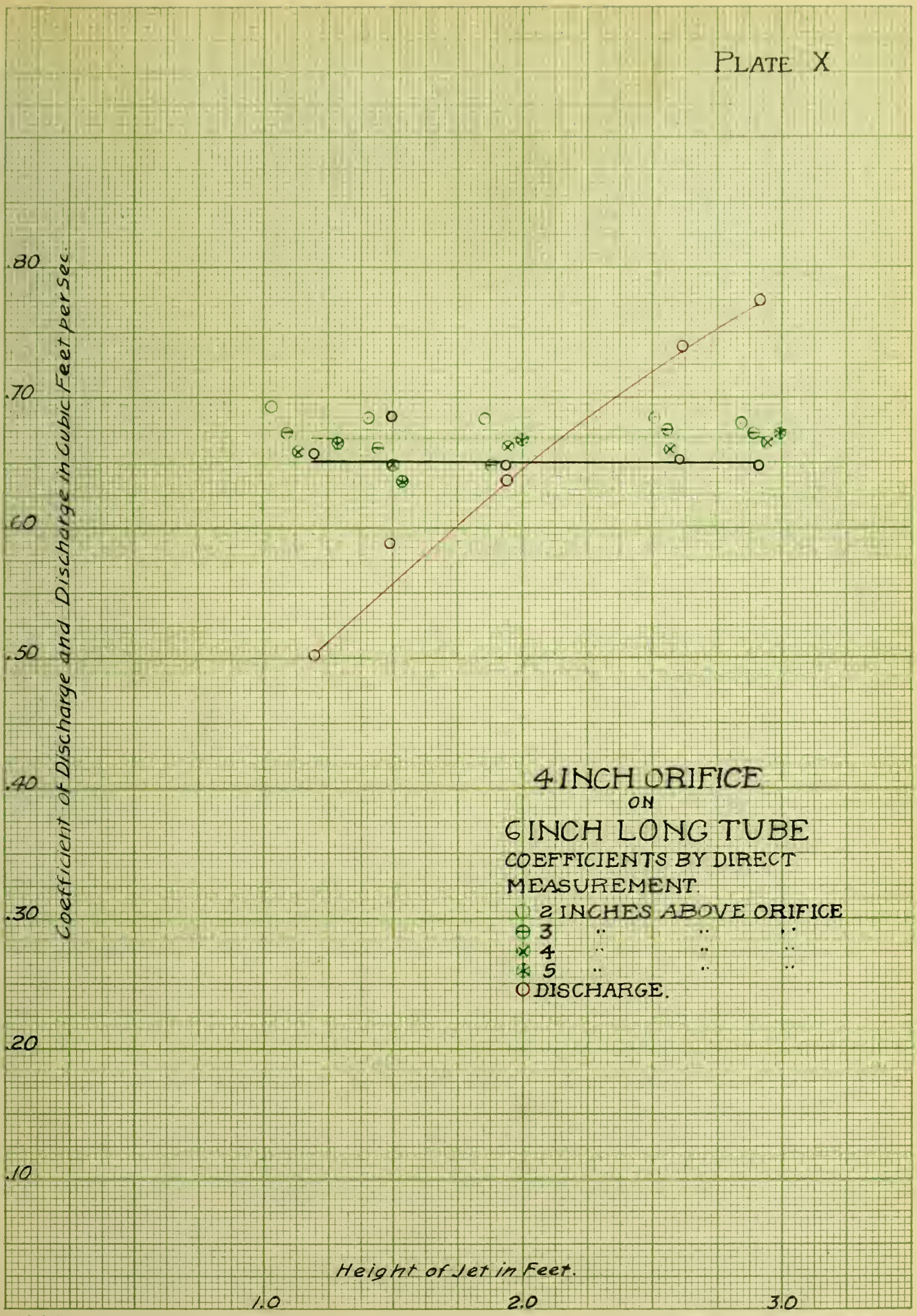
NO 346

PLATE IX



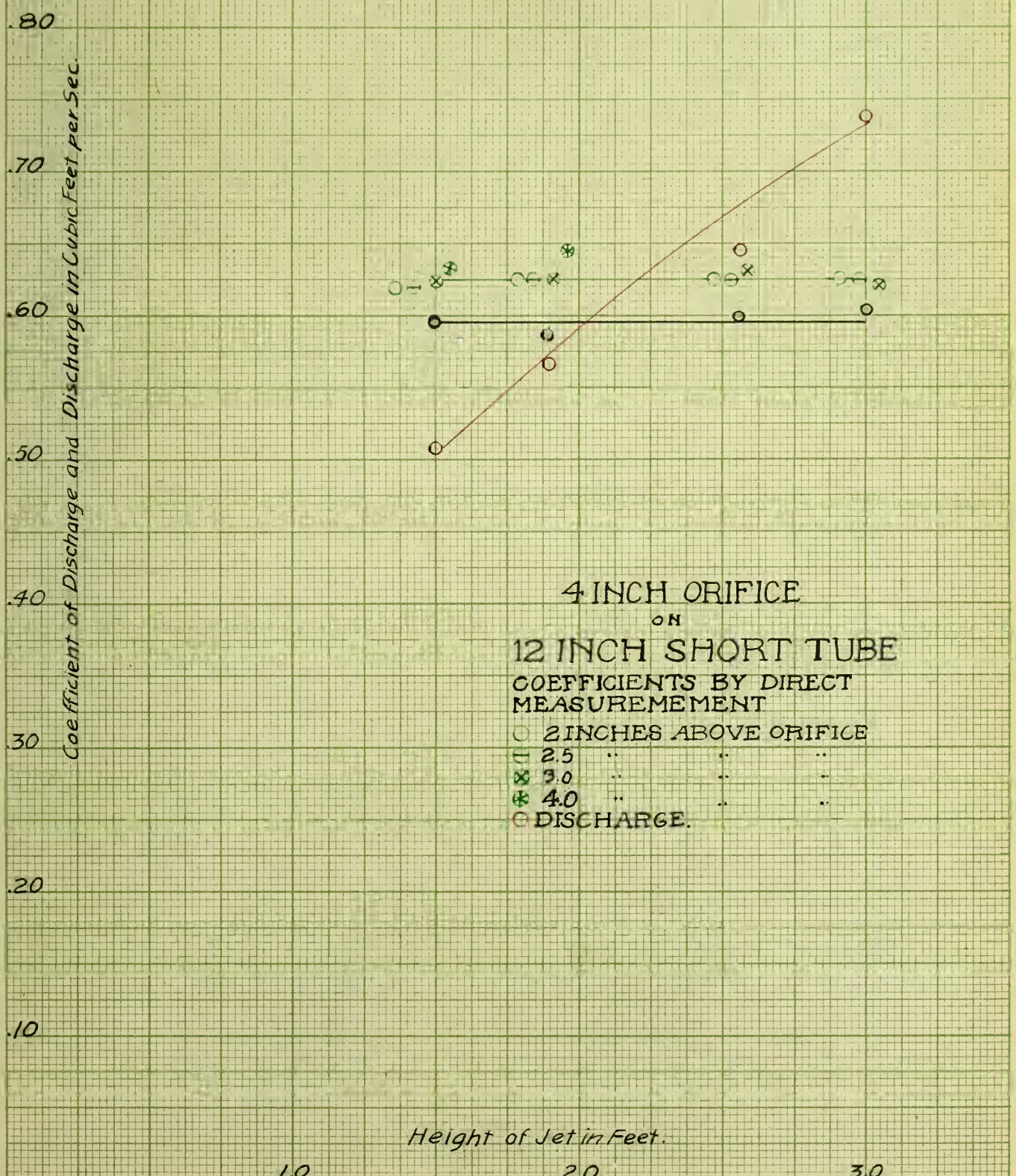
3 INCH ORIFICE
ON
6 INCH LONG TUBE
COEFFICIENTS BY DIRECT MEASUREMENT
○ 2 INCHES ABOVE ORIFICE
⊖ 3 " " "
⊗ 4 " " "
✱ 5 " " "
○ DISCHARGE

PLATE X



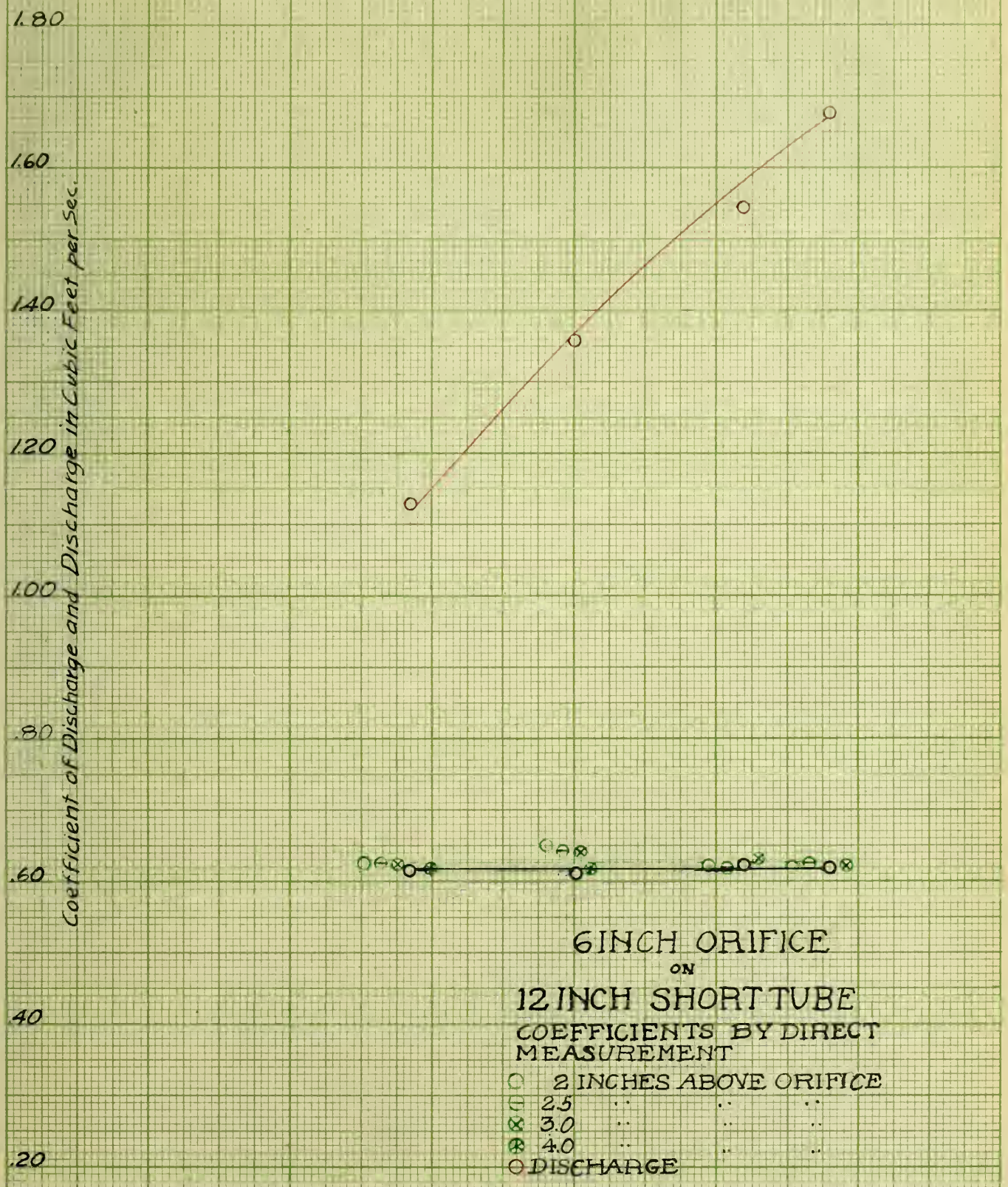
NO 346

PLATE XI



4 INCH ORIFICE
ON
12 INCH SHORT TUBE
COEFFICIENTS BY DIRECT MEASUREMEMENT
○ 2 INCHES ABOVE ORIFICE
□ 2.5 " " "
⊠ 3.0 " " "
✱ 4.0 " " "
○ DISCHARGE.

PLATE XII



6 INCH ORIFICE
ON
12 INCH SHORT TUBE
COEFFICIENTS BY DIRECT MEASUREMENT
○ 2 INCHES ABOVE ORIFICE
□ 2.5 " " "
⊗ 3.0 " " "
✱ 4.0 " " "
○ DISCHARGE

NO 346

PLATE XIII

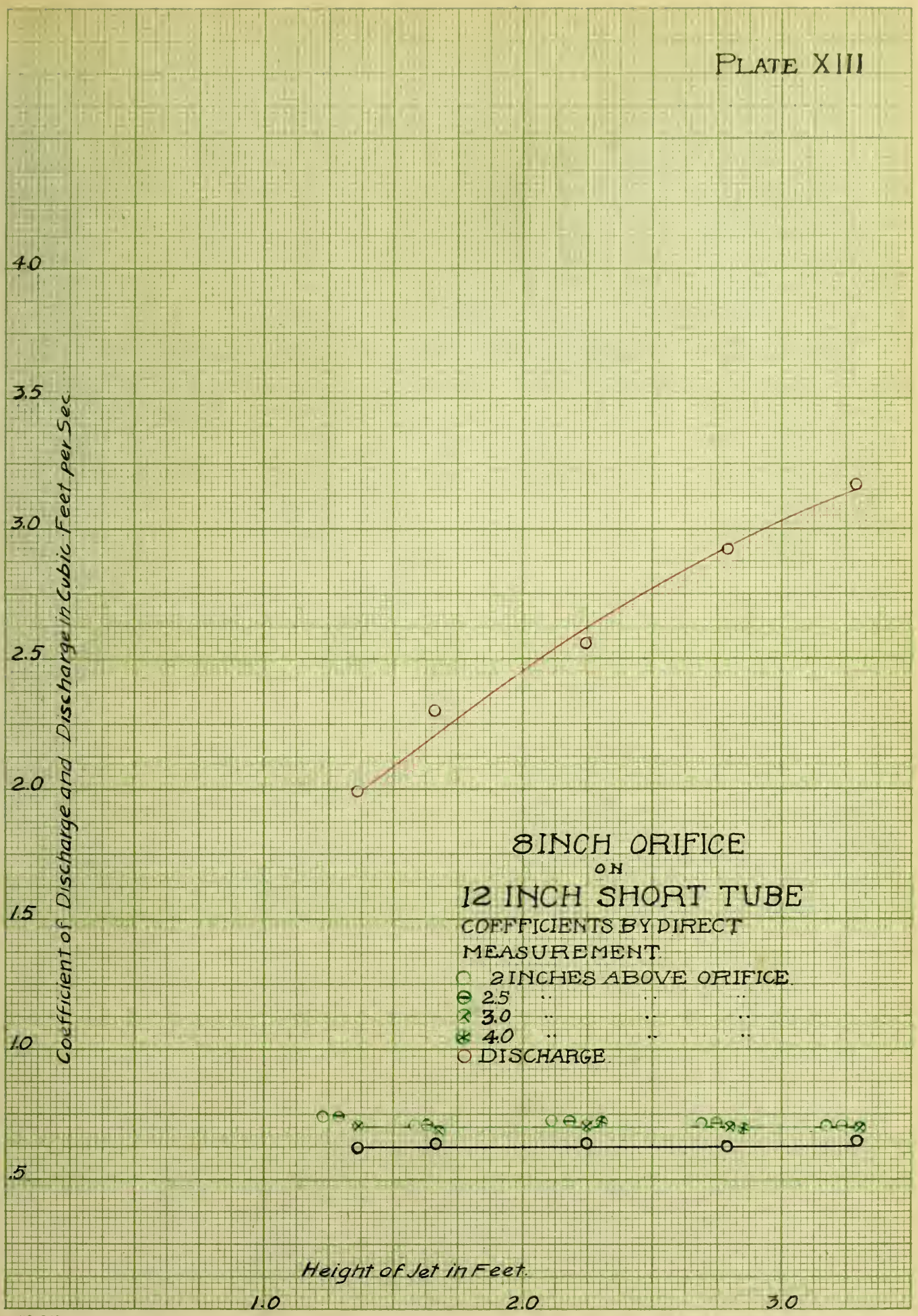
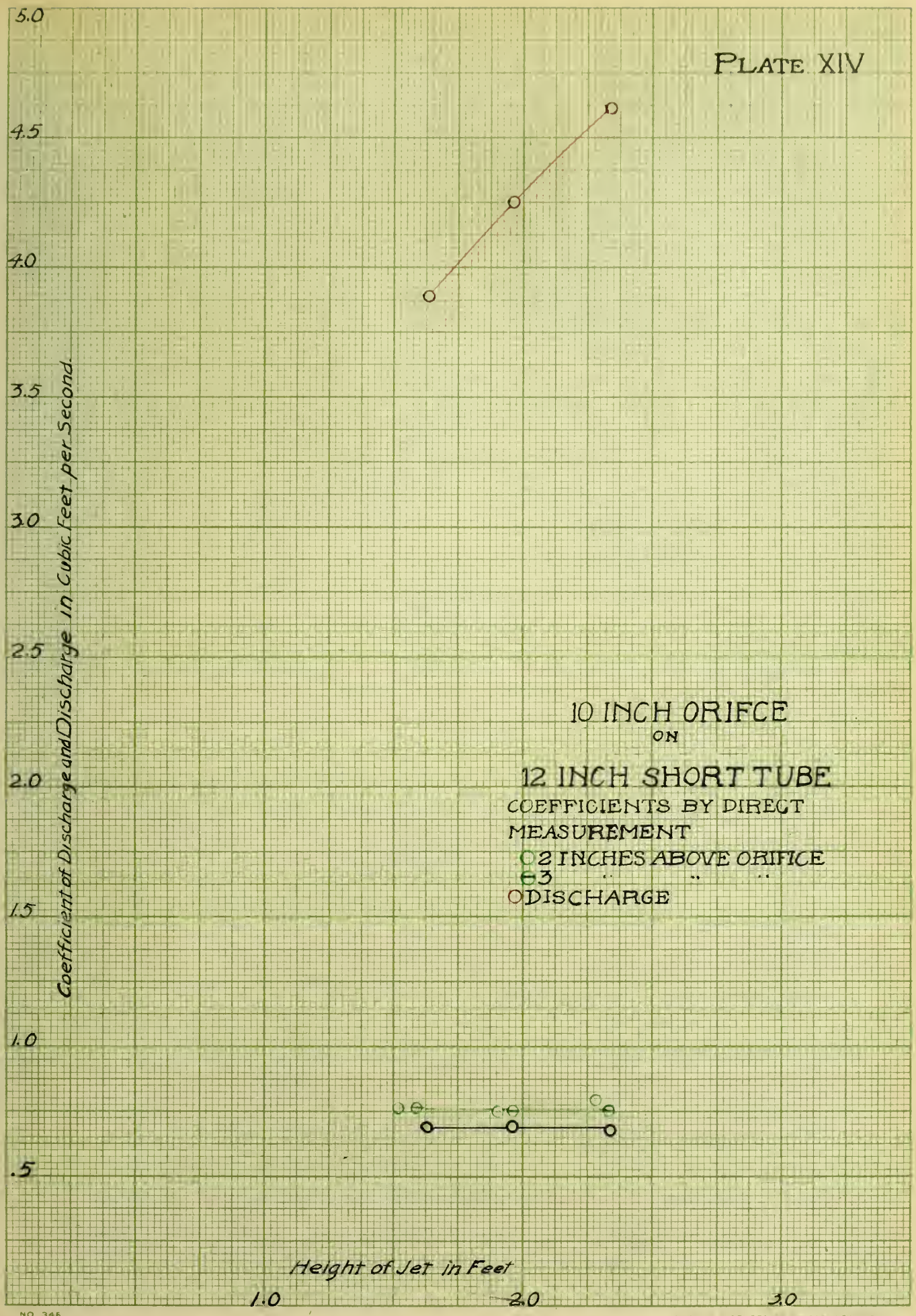
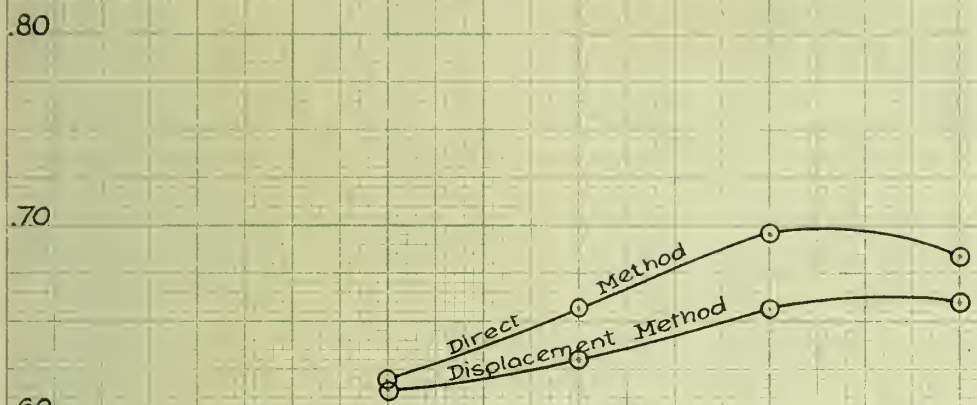

4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
Coefficient of Discharge and Discharge in Cubic Feet per Sec.
8 INCH ORIFICE
ON
12 INCH SHORT TUBE
COFFFICIENTS BY DIRECT
MEASUREMENT
2 INCHES ABOVE ORIFICE
2.5 " " "
3.0 " " "
4.0 " " "
DISCHARGE
Height of Jet in Feet.
1.0
2.0
3.0

PLATE XIV



NO 346

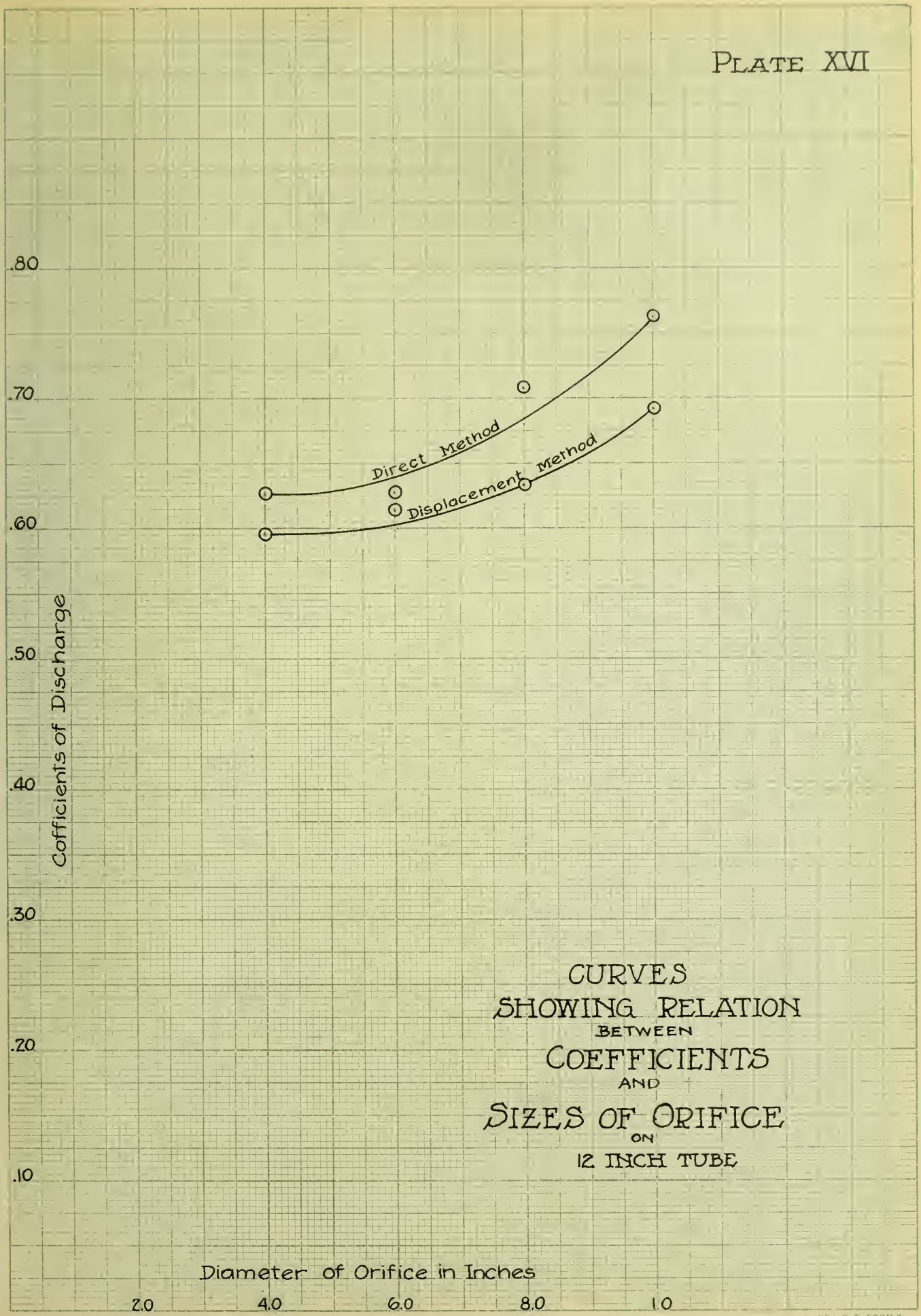
PLATE XV



CURVES SHOWING RELATION BETWEEN COEFFICIENTS AND SIZES OF ORIFICE ON 6 INCH TUBE

U. OF I. S. FORM 5

PLATE XVI



CURVES
SHOWING RELATION
BETWEEN
COEFFICIENTS
AND
SIZES OF ORIFICE
ON
12 INCH TUBE

OF S. S. FORM 3

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3 0112 079094766